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SUMMARY OF PAPER:

AREA NAVIGATION IMPLEMENTATION FOR A MICROCOMPUTER-BASED LORAN-C RECEIVER*

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The paper describes the development of an area navigation program and the implementation of this software on a microcomputer-based Loran-C receiver to provide high-quality, practical area navigation information for general aviation. This software provides range and bearing angle to a selected waypoint, cross-track error, course deviation indication (CDI), ground speed and estimated time of arrival at the waypoint. The range/bearing calculation, using an elliptical Earth model, provides very good accuracy; the error does not exceed more than 0.012 nm (range) or 0.09° (bearing) for a maximum range to 530 nm. The α-β filtering is applied in order to reduce the random noise on Loran-C raw data and in the ground speed calculation. Due to the α-β filtering, the ground speed calculation has good stability for constant or low-accelerative flight. The execution time of this software is approximately 0.2 second. Flight testing was done with a prototype Loran-C front-end receiver, with the Loran-C area navigation software demonstrating the ability to provide navigation for the pilot to any point in the Loran-C coverage area in true area navigation fashion without line-of-sight and range restriction typical of VOR area navigation.

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PAPER OUTLINE AND SCOPE

The following pages contain excerpts from Fujiko Oguri's paper. The scope and outline of the paper are shown below.

I. INTRODUCTION AND SUMMARY

II. PROBLEM DESCRIPTION

- A. Present-Day Navigation System
  1. VOR/DME system
  2. RNAV using VOR/DME system
  3. Other systems
- B. Low-altitude Navigation Using Loran-C

III. LORAN-C NAVIGATION

- A. Background
- B. Low Frequency System
- C. Loran-C Time Difference
- D. Computation of Time-Differences
- E. Converting Time-Difference
- F. Area Navigation

IV. COMPUTATION FOR AREA NAVIGATION

- A. Range and Bearing Angle
  1. Spherical model
  2. Simplified elliptical model
  3. Elliptical model
  4. Comparison among three models
- B. Other Navigational Information
  1. Cross-track error
  2. Ground speed and estimated time of arrival
- C. A Scheme for Microcomputer Use

V. THE MICROCOMPUTER SYSTEM

- A. A System Design
  1. Hardware
  2. Interfacing software
- B. Navigational Program
  1. Relationship among navigational programs
  2. RNAV program

VI. TESTS ON MICROCOMPUTER

- A. Testing with Simulations
- B. Flight Testing
  1. Filtering time differences
  2. Ground speed
  3. Range/bearing, CTE/CTEB and CDI indications

VII. CONCLUSIONS AND RECOMMENDATIONS

VIII. ACKNOWLEDGEMENTS

IX. REFERENCES

X. APPENDICES

- A. The Computation for An Area Navigation (RNAV) Equipment based on the use of VOR/DME
- B. Program Listing for Testing Range and Bearing Angle Computational Models
- C. Program Listing for Microprocessor Version of Area Navigation (RNAV) Program
- D. Program Listing for Testing Flight Test Data
- E. Program Listing for Testing Flight Test Data

PAPER EXCERPTS

The following excerpts (introduction, summary, conclusions, and recommendation sections) are shown on the following pages.

I. INTRODUCTION AND SUMMARY

This paper describes specific engineering work which has been done to make Loran-C a more useful and practical navigation system for general aviation. This work, in particular, deals with development of new software, and implementation of this software on a (MOS6502) microcomputer to provide high quality practical area navigation information directly to the pilot. Flight tests have been performed specifically to examine the efficacy of this new software. Final results were exceptionally good and clearly demonstrate the merits of this new Loran-C area navigation system.

LORAN-C (Long Range Navigation) is a hyperbolic, radio navigation system that has been in operation since 1958 [1]. It uses ground waves at low frequencies to provide positional information, not restricted to line-of-sight [2]. This system can be used in nearly all weather conditions to obtain position accuracies which are essentially independent of altitude. As of 1983, it is not yet a complete navigation system in the United States. In the midwest, which constitutes one third of the U.S. land area, coverage is deficient for some flight operations.

The VOR/DME (VHF Omni-directional Range/Distance Measuring Equipment) navigation system is well known as the contemporary, short-range navigation system which covers the whole United States with over 1000 stations, but this system is sensitive to siting and terrain, and has limits for low altitude coverage because VOR is a line-of-sight system. By relieving these shortcomings, Loran is considered to be a possible supplement for VOR/DME system [3].

The hyperbolic lines of position associated with Loran-C present a problem for the pilot. Historically, the hyperbolic lines of position do not convert readily to a meaningful display without comparatively high airborne equipment cost. However, the present availability of microprocessors makes low-cost airborne coordinate conversion equipment feasible. Contemporary technology provides for light-weight small-volume equipment with a low power drain for small aircraft. Thus, automatic Loran-C navigation can be made practical for general aviation users simply by making use of a microcomputer.

In this paper, work is described indicating rather elementary mechanizations that can provide the pilot very useful navigation at all altitudes. This development of software provides Area (Random) Navigation (RNAV) information from Time Differences (TDs) in raw form using an elliptical earth model and a spherical model. It is prepared for the microcomputer based Loran-C receiver which was developed at the Ohio University Avionics Engineering Center. In order to compute navigational information, a microcomputer(MOS6502) and a mathematical chip (Am9511A) were combined with the Ohio University Loran-C receiver. Final data in the report reveals that this software indeed provides accurate information with reasonable operation times.

VII. CONCLUSIONS AND RECOMMENDATIONS

Some specific conclusions can be reached as a result of the work performed in developing a microcomputer-based Loran-C receiver for general aviation application.

The objective of this area navigation software implementation is to provide high quality air navigation information by using Loran-C as a navigation system for general aviation. The following conclusions are made according to the test results in Chapter VI.

The conclusions are:

1. The high accuracy of the range/bearing calculation using the microcomputer-based Loran-C receiver was demonstrated; the error without a bias error does not exceed more than 0.012nm (range) or 0.09° (bearing) for ranges to 530nm.

2. Operational performance, as observed on a flight in a general aviation aircraft, is obtained using a α-β filter on time differences to reduce random noise. Filtering TDs with the new, stable clock, with an effective time constant is 4 seconds, effectively smooths the flight path and does not cause serious delay on the turns.

3. The ground speed calculation with 10 knots resolution has operational stability for a constant or low-acceleration flight. Since the ground speed calculation process passes through two filters, the ground speed cannot be easily updated with high acceleration. According to the effective time constants for the two filters (4 seconds for TDs and 12 seconds for the GS calculation), a step response becomes 86.3% of final value after 24 seconds. So the ground speed calculation can accept an acceleration which is less than $0.13nm/s^2$.

4. The CTE/CTEB indication provides the relative position and proper direction respectively to any desired course inside the Loran-C coverage area. Even with an airplane very close to a To waypoint (less than 0.1nm) the CTE has sufficent sensitivity to calculate an accurate CDI indication, while the VOR navigation system at close range is too sensitive.

5. An execution time of the total navigation system routine does not exceed more than 1.5 seconds, which is short enough for adequate position update information for air navigation. In the northeast U.S. chain (GRI=99600μs), the execution time is about 1.39 seconds for RNAV position updates.

6. The Loran-C navigation system with the new stable clock recorded an average bias error of 0.5nm which meets the requirement stated in AC90-45A (enroute 2.5nm, terminal 1.5nm). Even for an approach, this system has the capability to meet the total error of 0.6nm stated in AC90-45A.

7. The Loran-C area navigation software makes it possible for the general aviation user to fly to any point inside the Loran-C coverage area in true area navigation fashion unlike VOR navigation system with its line-of-sight and range restrictions.

Some problems were identified during the testing, and these should be addressed and solved prior to implementation by general aviation.

1. The bias error to the north is due to signal-strength differences of Loran-C stations and Avionics Engineering Center's receiver implementation. The bias error can be significantly reduced with a new RF front end [42] and applying propagation corrections. The recent tests with the new RF front end indicated a bias error of 0.2nm. These data were collected in the same area as the previous flight tests. The bias error of 0.2nm could be further reduced with the application of a propagation correction.

2. An improved ground speed response for accelerated flight. The ground speed response for accelerated flight can be improved by implementing a three dimensional filter [43]; however, improvement of measuring time differences to reduce random noise should be made to provide better data for ground speed calculations.

Contemporary microprocessor technology has greatly improved the capability for quality high navigation, and allows for achieving low-cost and light weight receivers for general aviation applications. This RNAV software promises to provide the pilot with significant operational advantages through the use of a microcomputer-based Loran-C receiver.